Cyclic Fatigue Resistance of Different Glide Path Files in Simulated Double Curved Canal in Continuous Rotary Motion: An In Vitro Study

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ABSTRACT

Aim: This in vitro study aimed to compare and evaluate the resistance to cyclic fatigue of a newly developed glide path file in a simulated double curvature canal in a cyclic fatigue-testing machine.

Methods: In this in vitro study, a static cyclic fatigue-testing machine with a simulated double curve was created and the samples were divided into the following three groups: Group I—HyFlex EDM; group II—TruNatomy file; and group III—Aurum G files and each instrument is continued to rotate in the canal and a number of cycles to failure (NCF) was calculated and Fractographic analysis was done using scanning electron microscope (SEM), and the results were statistically analyzed.

Results: Statistical analysis was done using parametric methods one-way analysis of variance (ANOVA) shows statistical significance between groups and then Tukey’s HSD post hoc tests were used for multiple pairwise comparisons. TruNatomy glide path files had the highest cyclic fatigue resistance when compared to HyFlex EDM and Aurum G files.

Conclusion: The selection of file systems in cleaning and shaping protocols is an enigma to endodontists. From the results of this study, it can be concluded that TruNatomy files had higher cyclic fatigue resistance than other glide path files are canals with double curvature, hence it is suitable for usage in root canals with extreme curvature.

Clinical significance: The selection of file systems in cleaning and shaping protocols is an enigma to endodontists. This in vitro study explored the selection protocols for the execution of root canal preparation. Heat treatment of nickel–titanium (NiTi) endodontic files had improved the cyclic fatigue resistance significantly enhancing the clinical life of file systems.

Keywords: Cyclic fatigue, Double curvature, Glide path files, TruNatomy files.

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INTRODUCTION

The success of endodontic treatment depends on the mechanical and chemical debridement of the root canals to clean their contents and reduce the bacterial load.1 Nickel–titanium (NiTi) instruments result in less canal transportation, dentin conservation, reduce the risk of zipping or stripping curved canals, and exhibit more elasticity and flexibility.2,3 Despite these advantages, NiTi instruments may fracture within the root canal without any sign of previous permanent deformation.4,5 Two different mechanisms have been identified for the fracture of rotary NiTi instruments; they are file separation due to torsional fatigue or cyclic fatigue.6 Cyclic fatigue fracture is caused by numerous stress and compression cycles at the site of greatest flexure when an instrument is rotating in a curve.7 Various NiTi alloy heat treatments have been proven to enhance cyclic fatigue resistance, and thus, several brands of NiTi instruments that have been fabricated from thermally treated NiTi alloys are available.8,9 Creating a glide path is an indispensable step to understanding the original anatomy of the root canal and provides less apical extrusion of debris and canal transportation.10,11

Glide path is an important step to decrease the stress of the NiTi instrument and thereby decreasing the chances of NiTi instruments fracturing within the canal.10,11 However, as with other rotary instruments, they are susceptible to fracture, especially because they are used at the beginning of root canal preparation when root canals are narrow. A recent study by De-Deus et al. reported that a high frequency of instrument fracture occurs when glide path preparation is done using mechanical rotary NiTi instruments than glide path preparation using hand files.12 One possible avenue is to improve instruments' performance by selecting new thermomechanically treated alloys or potentially safer kinematics intended to reduce the stress on files.13-15

The extent of the curvature in the area of operation is one of the most important variables that could lead to instrument fatigue fracture. Root canal curvatures should be measured, to facilitate
endodontic treatment planning, and in research, to reduce the risk of instrument separation.

The goal of the present study was to test the cyclic fatigue resistance in a double curvature (S-shaped) artificial root canal, described by Al-Sudani et al. where an artificial canal with a double curvature; the first coronal curve has 60° angle of curvature with a radius of 5 mm, located 8 mm from the tip of the instrument, and the second is apical with 70° angle and a radius of curvature of 2 mm whose center was placed at 2 mm from the tip. There is a lacunae for the cyclic fatigue resistance of newly introduced NiTi rotary instruments in extreme curvatures like a double curved canal in the static model. Hence the aim of the present study was to compare and evaluate the cyclic fatigue resistance of a newly developed glide path file in a simulated double (S-shaped) curvature canal in a cyclic fatigue-testing machine.

**Methodology**

**Ethical Approval**

The approval for the research was obtained from the committee for the student’s proposal, a constituent of the Institutional Ethical Committee of Sri Ramachandra Institute of Higher Education and Research (DU), Porur, Chennai (CSP/22/JUN/112/355).

**Sample Size Estimation and Source of Sample Collection**

Using G*Power software with the power of 80%, alpha error of 5%, and effect size (f) 0.48, a sample size of n = 10 per group were determined. Statistical significance is considered to be at p < 0.05 level.

**Materials and Methods**

A total of 10 instruments were selected for each file system and visually inspected under magnification. Defective samples were discarded and new instruments without any defects were used.

- **Group I:** HyFlex EDM (Coltene – Whaledent, Altstatten, Switzerland) (n = 10)
- **Group II:** TruNatomy files (Dentsply Sirona) (n = 10)
- **Group III:** Aurum G (META BIOMED, South Korea) (n = 10)

Each instrument was used in an artificial canal for testing cyclic fatigue resistance. All the instruments were rotated at the manufacturer’s, recommendations in a torque-controlled endodontic handpiece (X-Smart, Dentsply Maillefer) until fracture occurred. The electric handpiece was mounted upon a mobile device to allow precise and reproducible placement of each instrument inside the artificial canal. This ensured the three-dimensional alignment and positioning of the instrument to the same depth. A custom-made jig was attached to the testing device that consisted of artificial canals was manufactured. Jig with a simulated double curvature canal has the following specification; the first coronal curve with an angle of curvature of 60° and radius of 5 mm, located 8 mm from the tip of the instrument, and the second is apical with a 70° angle and 2-mm radius of curvature, the center of which was placed at 2 mm from the tip.

The instrument was placed inside the artificial canal till its full length and then rotated freely to avoid any torsional fatigue. Back and forth movements were not employed. All instruments were rotated until the fracture occurred; the time required for the fracture was noted with a digital clock. The number of cycles to failure (NCF) was calculated to the nearest whole number; NCF = revolution per minute (rpm) × time (seconds)/60. And the Fractographic analysis of fractured instruments was evaluated using scanning electron microscopy (SEM) and one sample from each group was analyzed using JEOL JSM-IT800 at a magnification of 250X.

**Statistical Analysis**

The results were statistically analyzed, and the normality tests Kolmogorov–Smirnov and Shapiro–Wilk tests results revealed that the variables follow Normal distribution. Therefore, the data parametric methods were applied. To compare the mean values between groups one way analysis of variance (ANOVA) is applied followed by Tukey’s HSD post hoc tests for multiple pairwise comparisons. The statistical analysis was performed using statistical package for the social sciences (SPSS) (IBM SPSS Statistics for Windows, version 26.0, IBM Corp., Armonk, NY; Released 2019) is used. The significance level is fixed as 5% (α = 0.05).

**Results**

The mean value of the NCF for HyFlex EDM was 861.0 and for TruNatomy files was 950.70 and for Aurum G files was 166.0 (Appendix) and the statistical analysis by one-way ANOVA comparison showed that mean NCF was significantly higher in TruNatomy files followed by HyFlex EDM and Aurum G files between each group with p-value less than 0.05 (Table 1).

Turkey HSD post hoc tests were conducted for multiple pairwise comparisons between each group and it showed a significant difference with p < 0.05 (Table 2). From the results of the present study, it was inferred that TruNatomy files showed a significantly higher cycle fatigue resistance followed by HyFlex EDM, and Aurum G files showed the least cyclic fatigue resistance.

**Table 1:** Comparison of mean NCF values across the S-shaped curvature of the root canal system using one-way ANOVA

<table>
<thead>
<tr>
<th>Group</th>
<th>NCF values</th>
<th>Mean NCF</th>
<th>Standard deviation (SD)</th>
<th>95% confidence interval (CI) mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>HyFlex EDM</td>
<td>10</td>
<td>861.00</td>
<td>29.040</td>
<td>840.23 – 881.77</td>
</tr>
<tr>
<td>TruNatomy</td>
<td>10</td>
<td>950.70</td>
<td>26.758</td>
<td>931.56 – 969.84</td>
</tr>
<tr>
<td>Aurum G</td>
<td>10</td>
<td>166.00</td>
<td>14.682</td>
<td>155.50 – 176.50</td>
</tr>
</tbody>
</table>

**Table 2:** Comparison of mean NCF values across the S-shaped curvature of the root canal system for multiple comparisons using Tukey HSD post hoc test

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Mean difference</th>
<th>p-value</th>
<th>95% CI difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean NCF values</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HyFlex EDM</td>
<td>861.00</td>
<td>−89.70</td>
<td>&lt;0.001</td>
<td>−116.67 to −62.73</td>
</tr>
<tr>
<td>TruNatomy</td>
<td>950.70</td>
<td>695.00</td>
<td>&lt;0.001</td>
<td>668.03 to 721.97</td>
</tr>
<tr>
<td>Aurum G</td>
<td>166.00</td>
<td>784.70</td>
<td>&lt;0.001</td>
<td>757.73 to 811.67</td>
</tr>
</tbody>
</table>
The SEM Analysis

The SEM analysis was done using JEOL JSM-IT800 at a magnification of 250X, and the SEM images of all broken segments showed the ductile fracture of cyclic fatigue failure in all the groups (Fig. 1).

Discussion

The occurrence of double curvature in endodontic treatment is between 50 and 60% in posterior teeth. Curved or dilacerated root canals exhibit great difficulty in cleaning, shaping, and obturation of the root canal system; therefore, determining the degree of curvature of the root canal before starting the endodontic treatment is mandatory. The prevalence of dilacerations ranges from 0.32 to 30.9% where the maxillary arch is affected more than the mandibular arch. Furthermore, permanent teeth are affected more frequently than primary teeth and posterior teeth more than anterior teeth with no gender predilection.

Regarding the double-curved canals preservation of the original canal shape is important. Therefore, conservative shaping of the canals is essential to avoid the possibility of ledges, perforations, and transportation of the apexes. Double curved canal requires flexible instruments for preparation, hence glide path files were used. The glide path preparation with NiTi mechanical instruments is related to reduced canal transportation and deviation when compared to manual files, besides being less time-consuming. Therefore, manufacturers are developing new glide path systems with adequate kinematics and heat-treated alloys.

Cheung et al. classified most of the fractured instruments analyzed as a cyclic failure, implying fatigue is the predominant mechanism for material failure. Material fatigue occurs due to the microcracks produced during the manufacturing process. Thus, once a microcrack is initiated, it can quickly propagate to cause cyclic failure.

The fatigue-testing device manufactured for this study consisted of a main frame which was connected mobile support for the handpiece and also with stainless steel block which contains simulated artificial canals. The dental handpiece was mounted upon a mobile device that allowed for precise and simple placement of each instrument inside the artificial canal, ensuring 3D alignment and positioning of the instruments to the same depth. Artificial double-curved canals were designed to accommodate each instrument in terms of size and taper, thus providing the instrument with a suitable trajectory and permitting free rotation of the instruments while generating minimal torque values. The artificial canals were covered with tempered glass to prevent the instruments from slipping out and to allow for visualization of fracture of the instruments. According to the Canadian Academy of Endodontics in 2017 excessive root canal curvature has been listed as a risk factor that may affect the endodontic treatment outcome.

Electropolishing renders a more homogeneous surface oxide layer, with fewer defects and residual surface stress. In the process, the corrosion resistance of the metal is enhanced along with improved surface characteristics. Lopes et al. found that electropolished instruments demonstrated significant increases in cyclic fatigue resistance. Condorelli et al. identified the same type of increased resistance to cyclic fatigue with the electropolished instruments after performing thermal treatments. The thermal applications did not alter instrument surface morphology but resulted in significant changes in the instrument bulk with the appearance of an R-phase and improved fatigue resistance. Hence, Aurum G with Alternating Cutting Edge was used in this study to compare the effect of electropolishing with the other manufacturing processes.

TruNatomy combines Swiss precision with advanced engineering to offer the benefits of improved performance with increased respect for the tooth anatomy. The TruNatomy Glider files operate at a high speed for greater cutting efficiency with minimal torque. With only 2 cutting edges, and so it encounters less resistance and thus requires less pressure, ensuring more precise with increased ease of use. The thermal treatment provides greater flexibility with improved fatigue resistance. Hence, TruNatomy Glider was used in this study to compare with the other manufacturing processes.

Electrical Discharge Machining is a unique process of making files. Workpieces are machined in the EDM manufacturing process by generating a potential between the workpiece and the tool. The sparks created in EDM cause the surface of the material to melt and evaporate. EDM creates the unique surface of the NiTi instrument and makes it stronger and more fracture resistant. This unique combination of fracture resistance and flexibility makes it possible to reduce the number of files require root canal treatment with preservation of the root canal anatomy. Hence, HyFlex EDM was used in this study to compare with the other files.

The SEM evaluation images of the fractured surface showed the features of cyclic fatigue/ductile failure for all instruments. All the instruments show fractured surfaces with microvoids in the file fragment, and it is a mechanical characteristic of ductile fracture. Wide-ranging forms of dimples were identified and no plastic deformations in the shaft of the fractured instruments were observed. Trunatomy instruments showed a parallelogram cross-section design while HyFlex EDM instruments revealed a square cross-section design, and Aurum G instruments revealed a triangular cross-section design.
The results showed that the difference in mean values for cyclic fatigue resistance was significant with all the three groups. It was observed in our study that cyclic fatigue resistance was higher in TruNatomy files. This could be probably due to the slim shape combined with a unique cross-section for better performance while providing more space for thorough debris debridement. A slim NiTi wire design of 0.8 mm used instead of up to 1.2 mm wire. Generic variable tapered files and off-centered cross-section. TruNatomy instrument is made of special NiTi heat-treated wire that provides an exceptional flexibility, which allows the file to be pre-bent when needed. Therefore, it is difficult to determine whether there is a crucial effect of a single factor or, more likely, a combination of different correlated factors in determining the final mechanical properties of TruNatomy files.

Aurum G showed the least cyclic fatigue resistance. The fact that HyFlex EDM showed a better fatigue resistance than Aurum G might be a result of the extreme flexibility and shape memory of HyFlex EDM files making them very advantageous in curved canals.

**Limitations**

Artificial stainless steel double-curved canal was used in the current study, which does not depict the real clinical scenario. In clinical practice, the axial movement of the handpiece was controlled manually and these variables were difficult to replicate in this in vitro study.

**Future Scope**

Since it is an in vitro study, the results cannot be directly applicable to a clinical scenario; hence further clinical investigations are required to confirm the results of the present study.

**Conclusion**

Within the limitations of this study, it can be concluded that TruNatomy glide path files had the highest cyclic fatigue resistance when compared to HyFlex EDM and Aurum G files and it is statistically significant. And HyFlex EDM glide path files had lower cyclic fatigue resistance than TruNatomy glide path files but superior cyclic fatigue resistance than Aurum G files. And Aurum G file system had the least fatigue resistance. Hence, TruNatomy glide path files can be considered as a potent file of choice in double curved or dilacerated root canals.

**References**